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Title: Stabilizing a laboratory plasma column beyond the external kink limit

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Intended for: invited colloquim

Stabilizing a laboratory plasma column beyond the external kink limit

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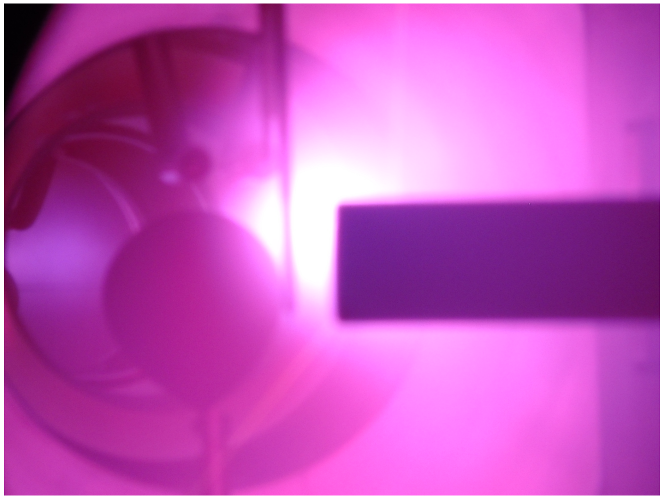
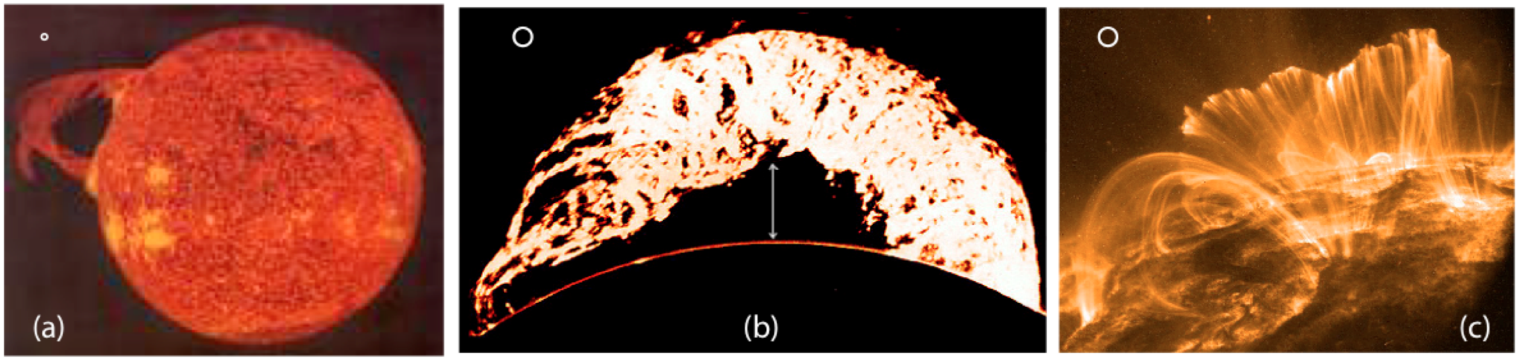


emerging flux ropes may also display kink instabilities



the sawtooth in a tokamak is also a kink mode

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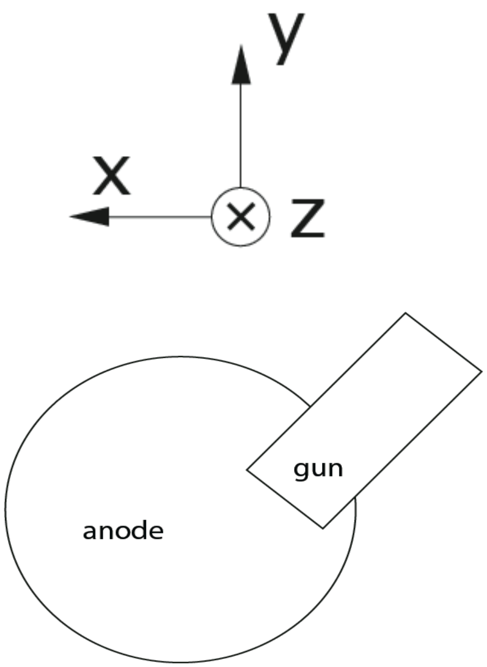
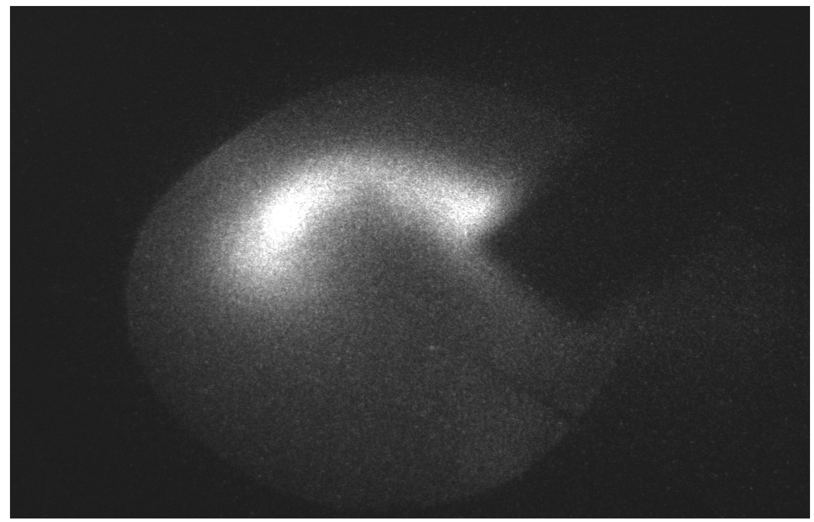
the RSX current-driven kink mode saturates at finite amplitude



axial perspective

the kink gyrates at a steady rate, indefinitely



do kink instabilities in astrophysical flux ropes also saturate?

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in this talk:

- kink instability from field line twist
- potential causes of saturation of the kink instability
- Reconnection Scaling Experiment (RSX)
- 3D measurements suggest current above the kink threshold; present insight

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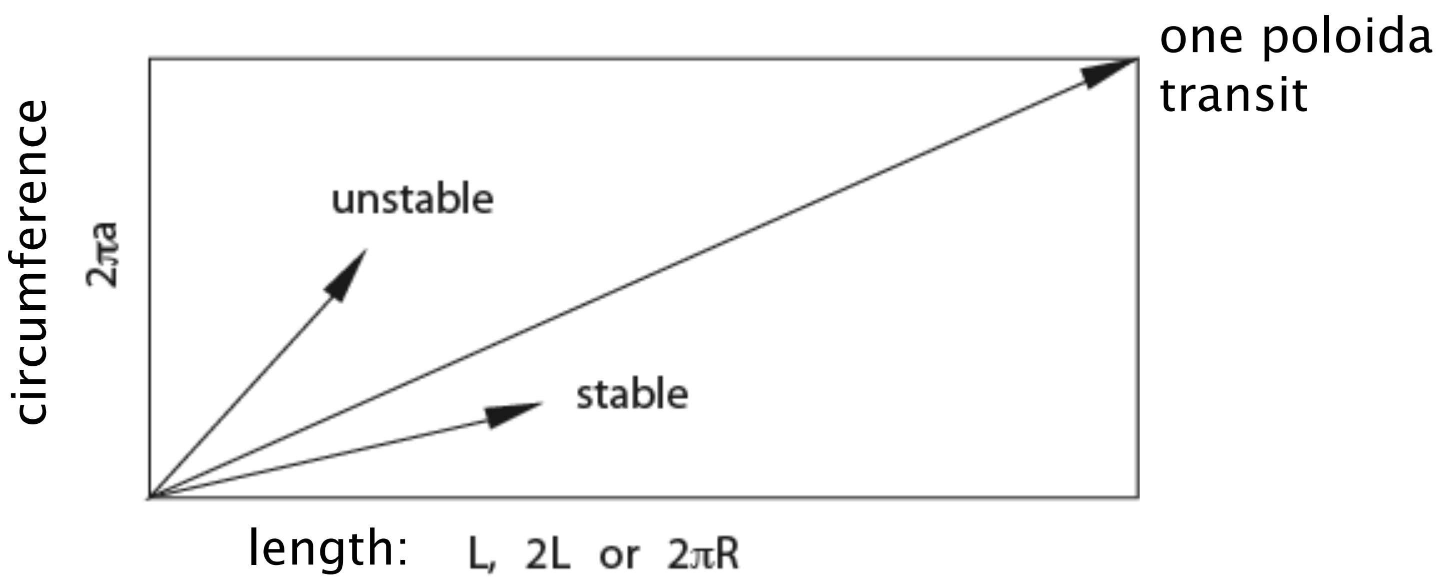
the kink arises when twist in magnetic field is too great (linear model)

$$J_{ks} = \frac{4\pi B}{\mu_0 L}$$



the kink handedness is paramagnetic
kink pitch is not constant
flow causes gyration; sense depends on k/|k|
growth is unbounded

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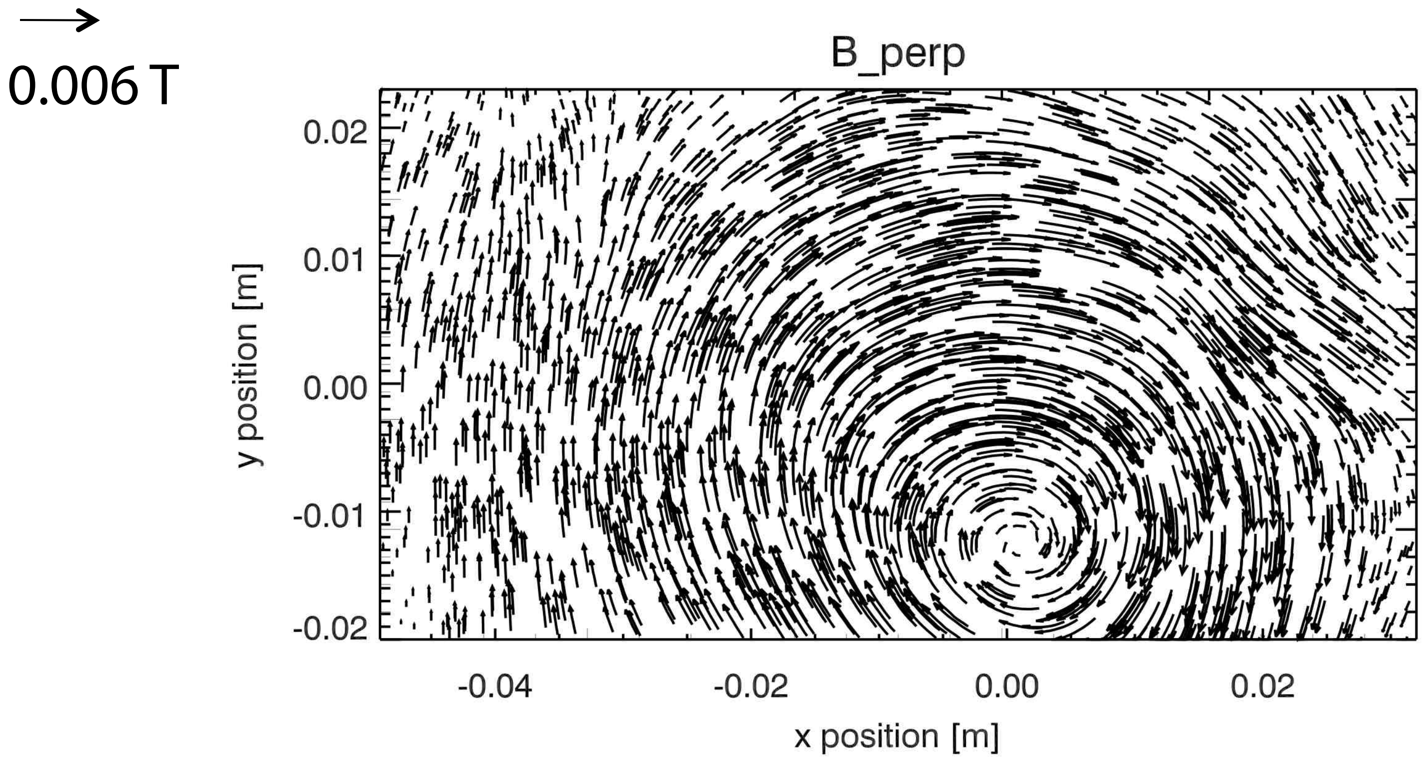
Bperp is measured over entire cross-section



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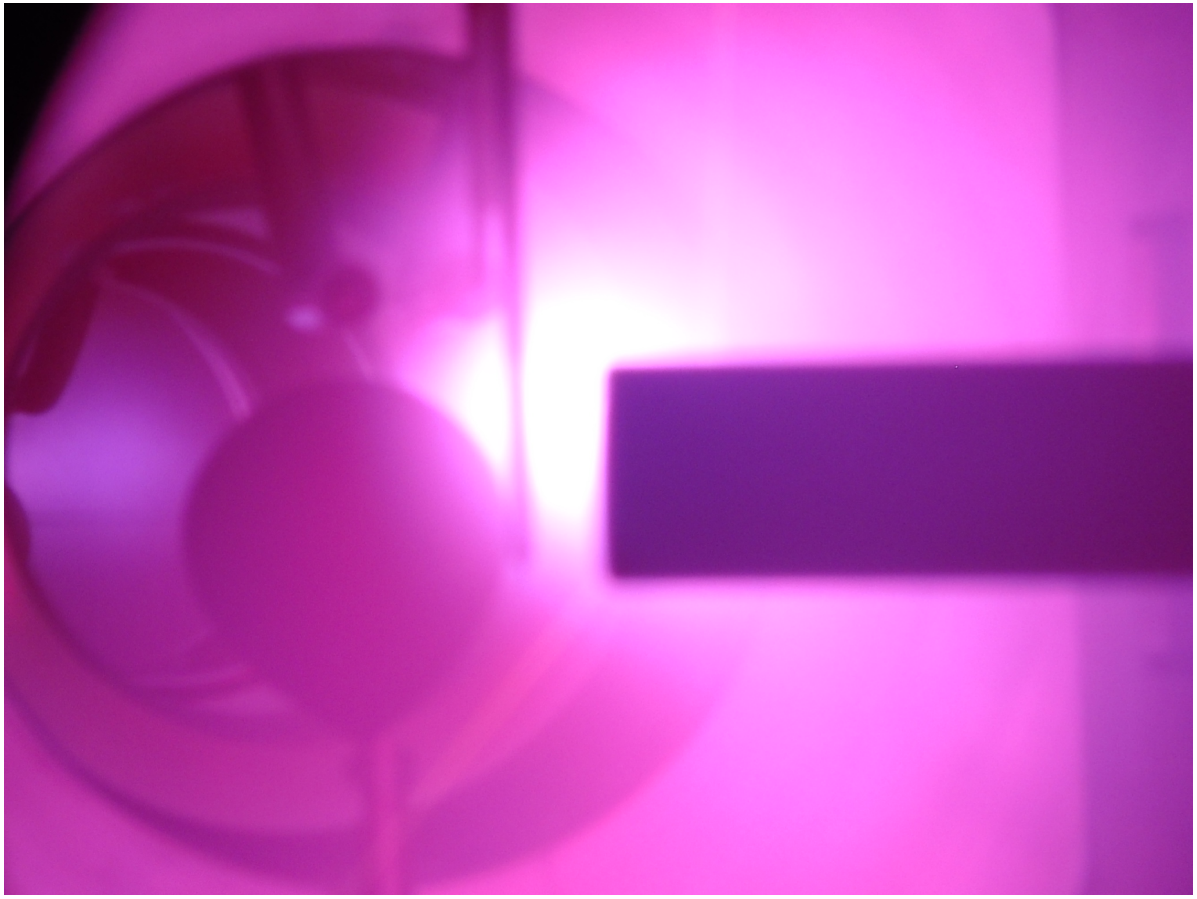
in RSX under precise conditions, the kink can persist at small amplitudes for long timescales

potential causes of saturation

conductive wall (image current feedback)
aperiodicity (tension from line-tied footpoints)
nonlinear MHD (finite amplitude)
two-fluid effects (separation of mass and current)
kinetic effects (collisionality is weak)
secondary instabilities (gravity, islands)

geometry of the gun/anode/diagnostic system

slow, visible light image of a discharge



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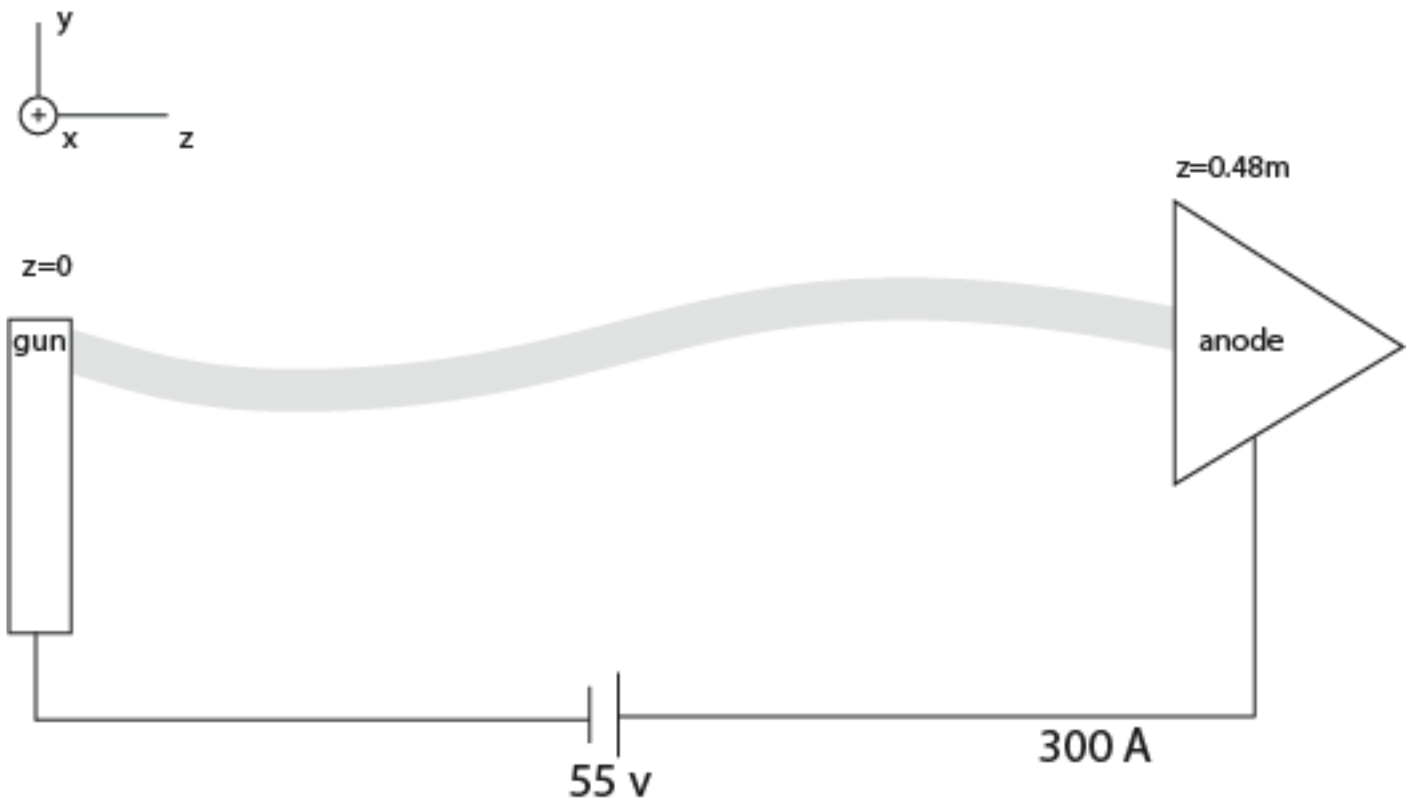
geometry of the gun/anode/diagnostic system



plots in this talk will be in xy planes at various z

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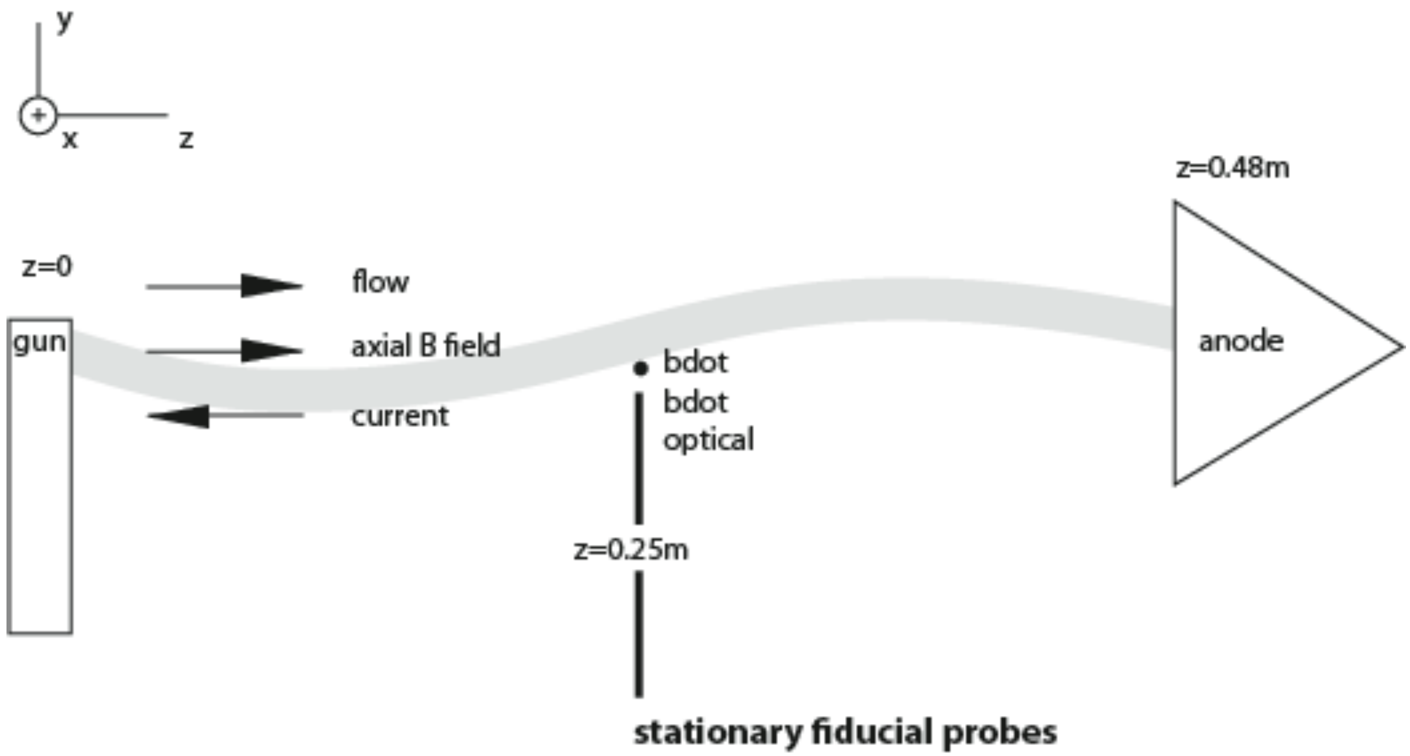
geometry of the gun/anode/diagnostic system

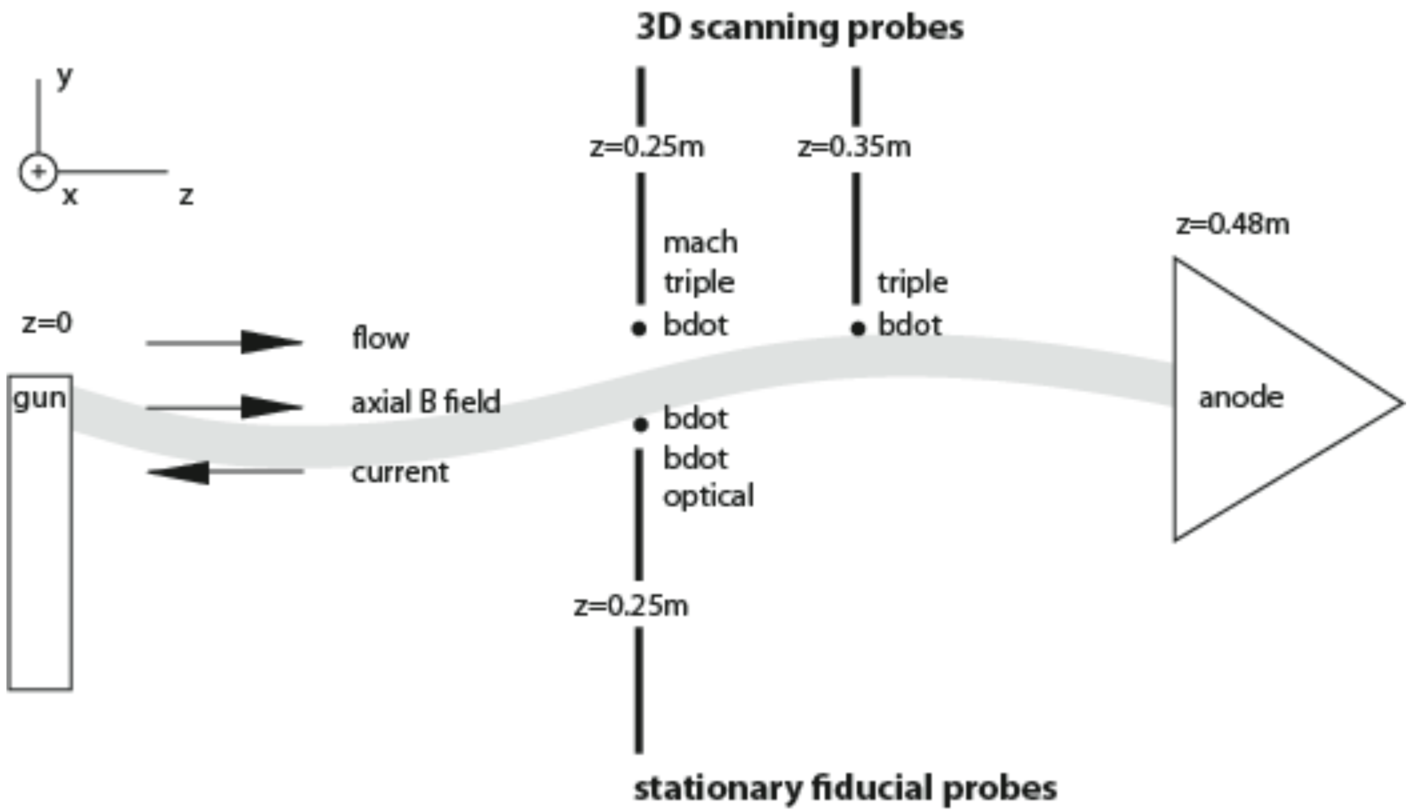
current opposite field leads to left-handed kinks

geometry of the gun/anode/diagnostic system



stationary probes serve to register time base between shots

geometry of the gun/anode/diagnostic system



a 3D volume is reachable
stationary probes serve to register time base between shots
plots in this talk will be in xy planes at various z

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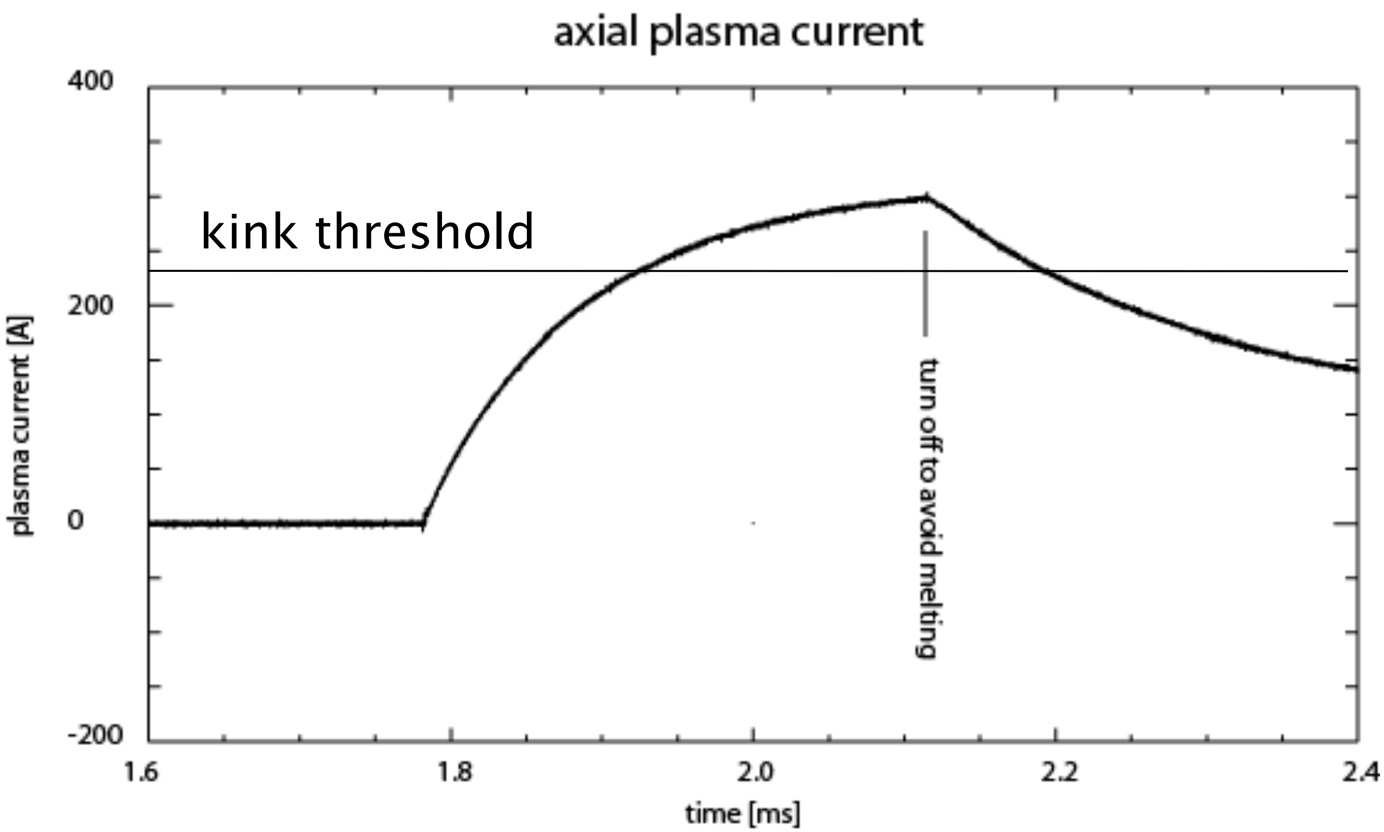
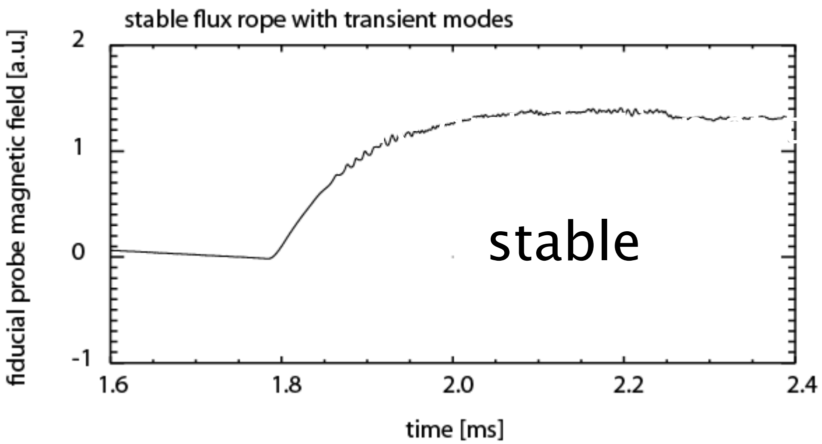
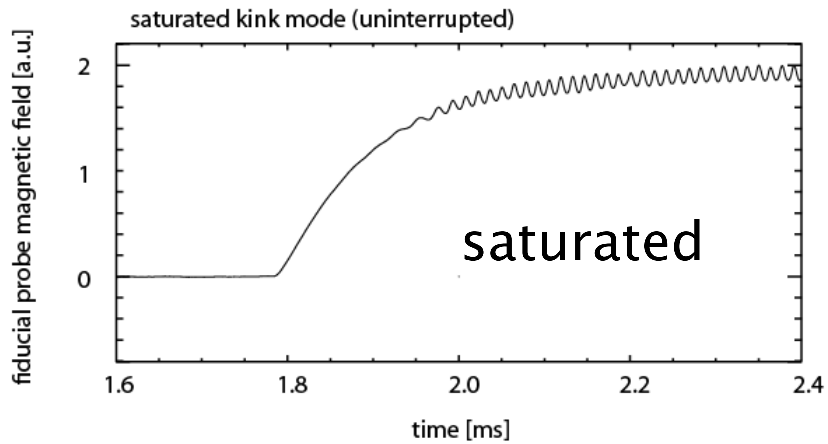
A plasma current is set up just beyond the external kink limit

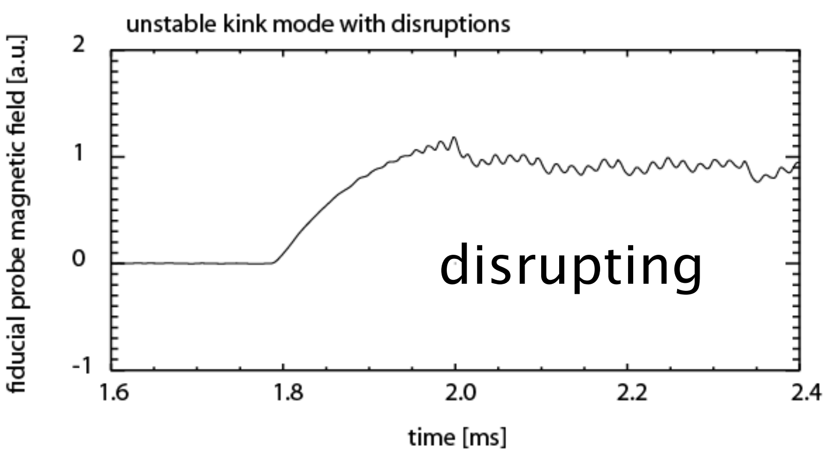


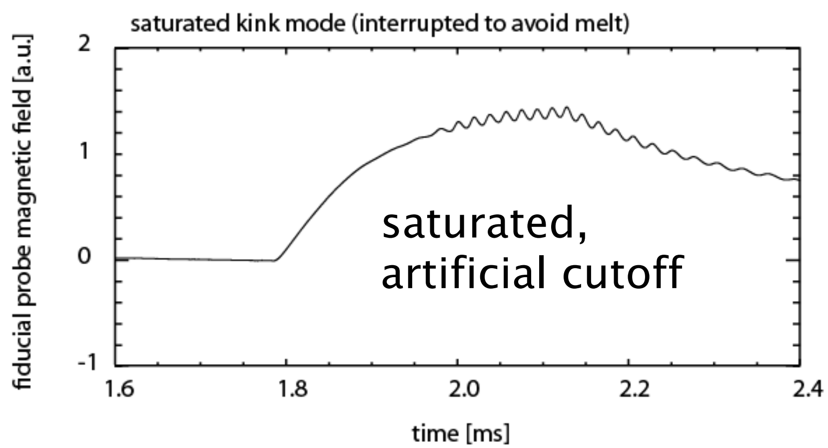
axial magnetic field (300 G) is essentially static
plasma turns on at early time
plasma current drawn once discharge established
plasma current terminated early to avoid melt

the flux rope can stay stable, disrupt, or attain a saturated oscillation









marginal stability threshold depends on line-tiedness
high frequency mode sometimes appears
disruption occurs when flux rope jumps over anode
experiment artificially shortened to avoid melt damage

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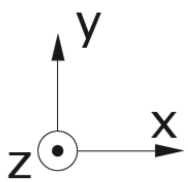
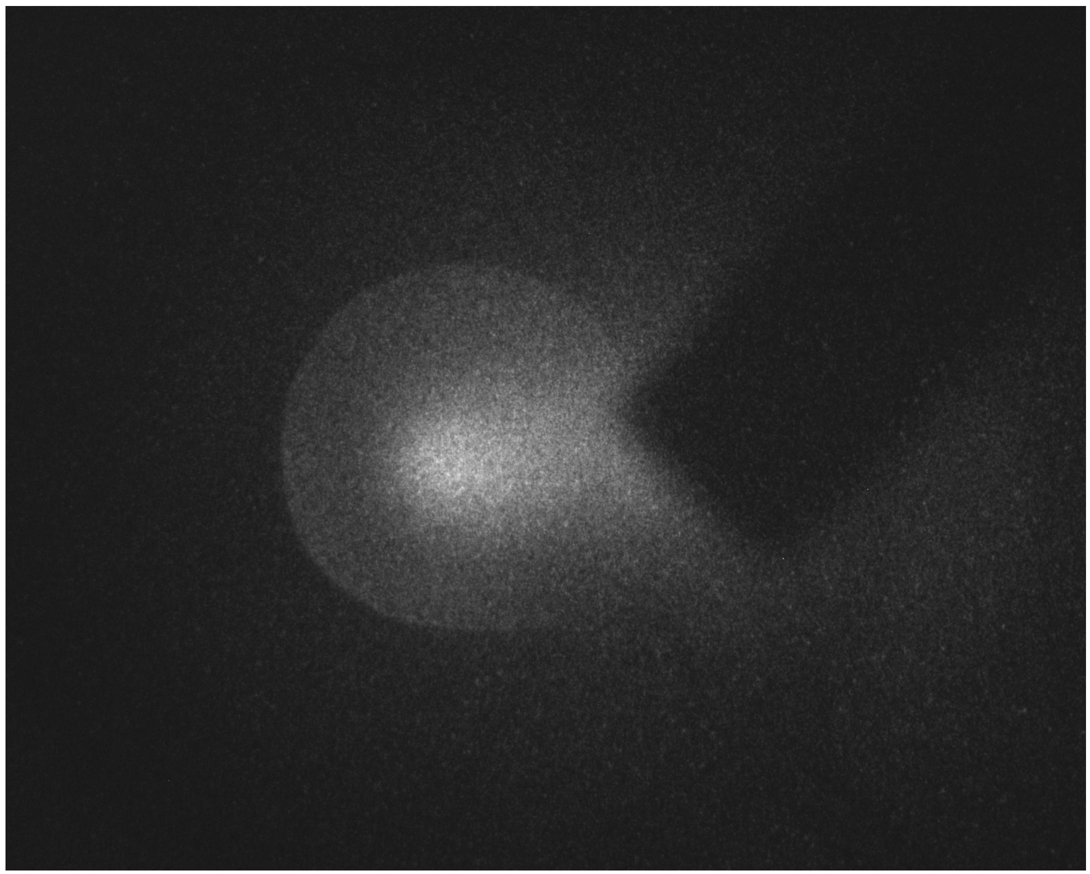
disruption of kink unstable flux rope with unbounded growth beyond anode, end view





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conditional sampling composites structure over many repeatable discharges

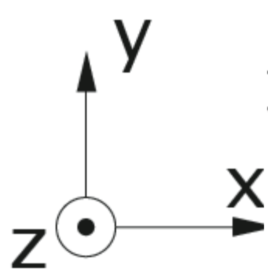
fiducial probes capture onset of event (gyrating flux rope)

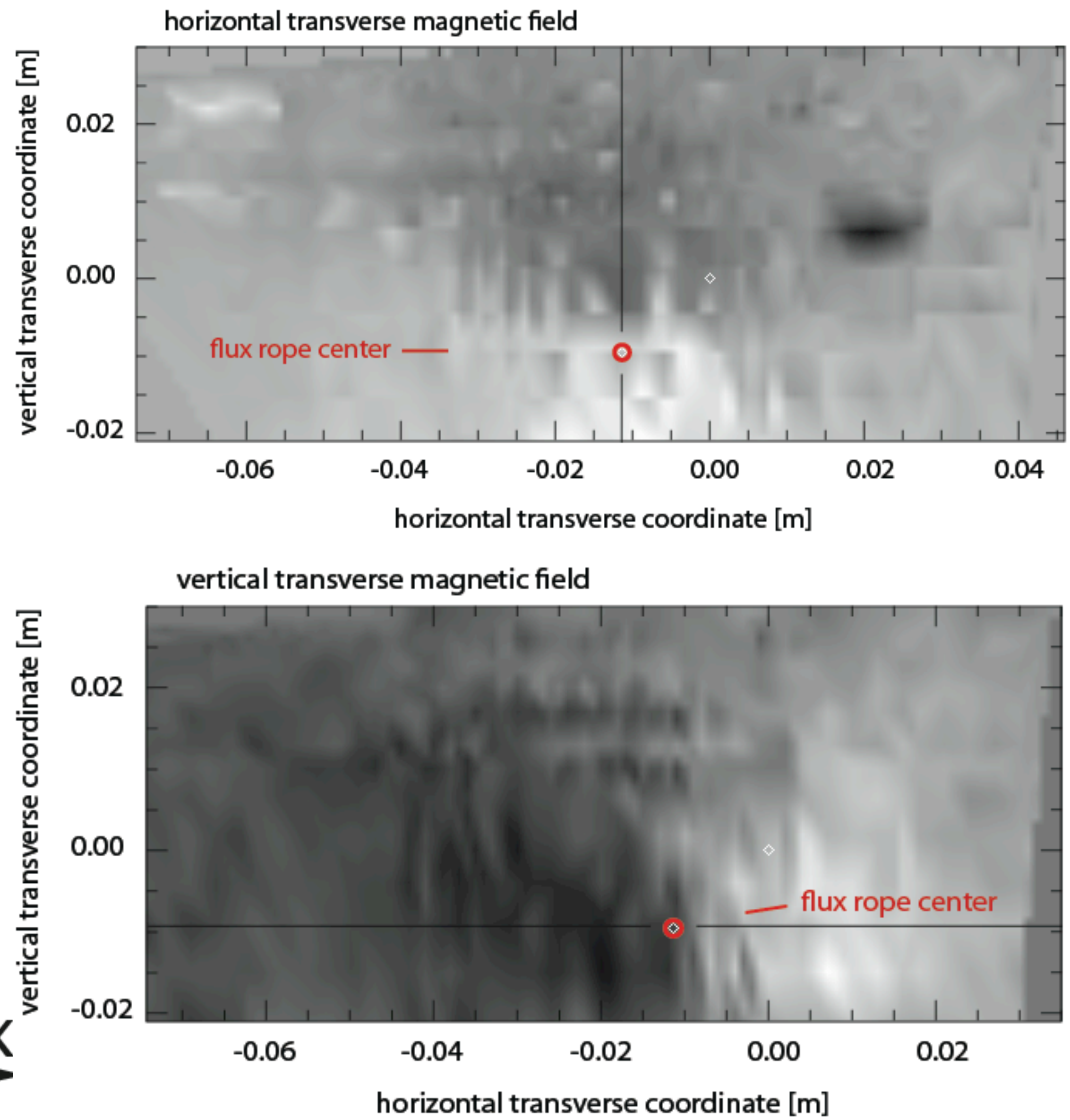
event is aligned in time from shot to shot

scanned probes sample 3D volume over series of shots

3D sequence is measured

center of gyration and sense of rotation is established





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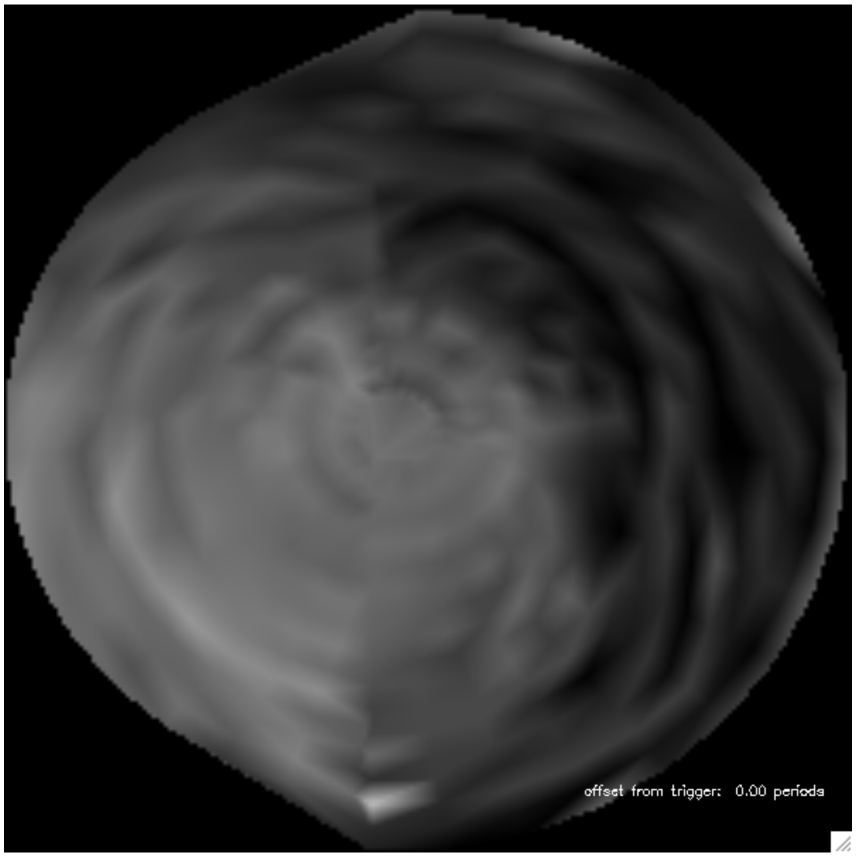
the mach number has a much broader distribution than the density

mach number distribution (white is 1)



shear in flow may generate quadrupole signature (see Intrator, next talk)

shear may also lead to secondary instabilities

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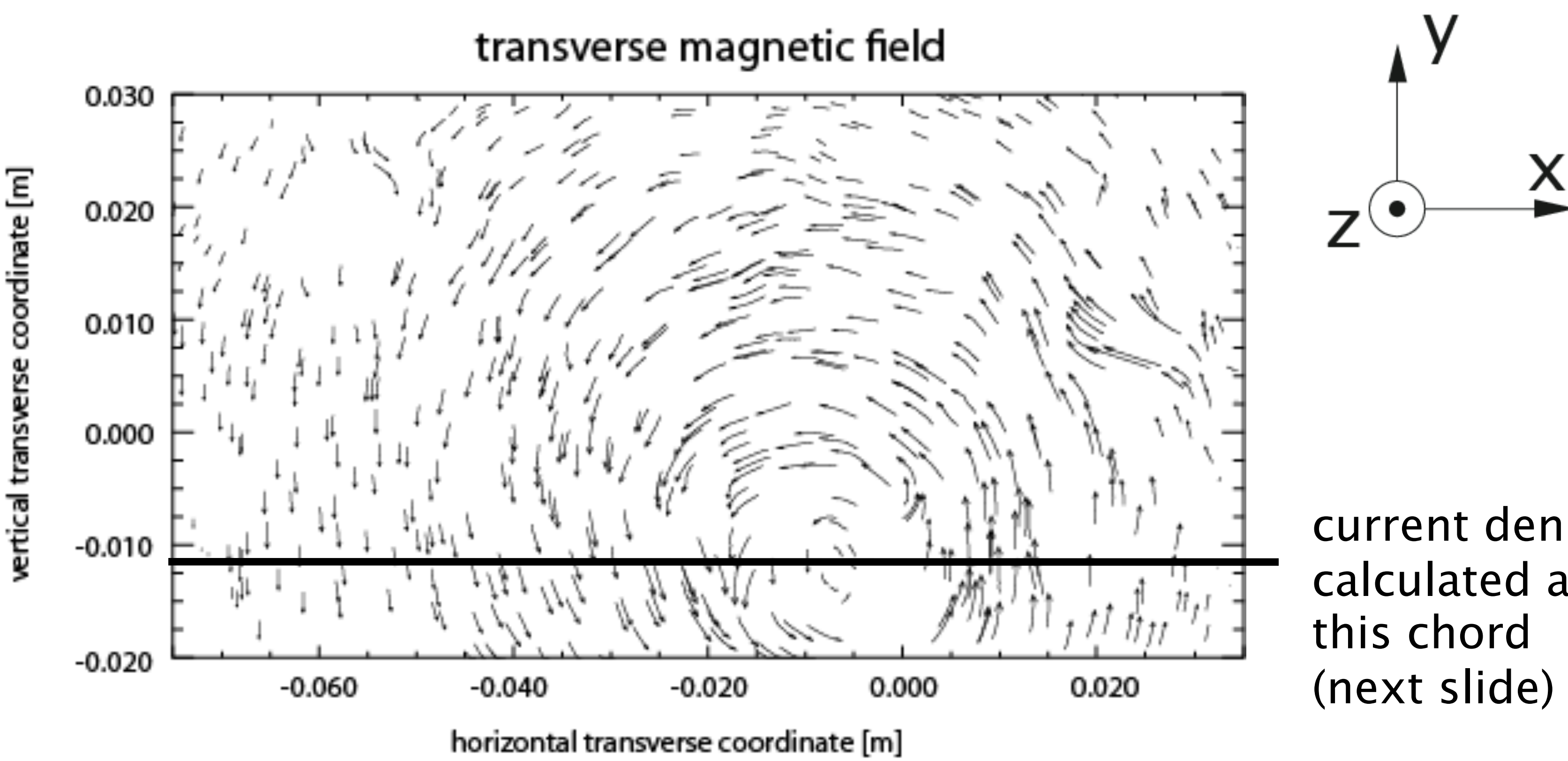
combining horizontal and vertical measured fields shows a magnetic profile expected for a compact current profile



current density calculated along this chord (next slide)

physics outline

problem: the kink saturates at steady, finite amplitude

explanations:

internal vs external

wall stabilization

effect of flow

momentum balance

bifurcated equilibria

inertial forces

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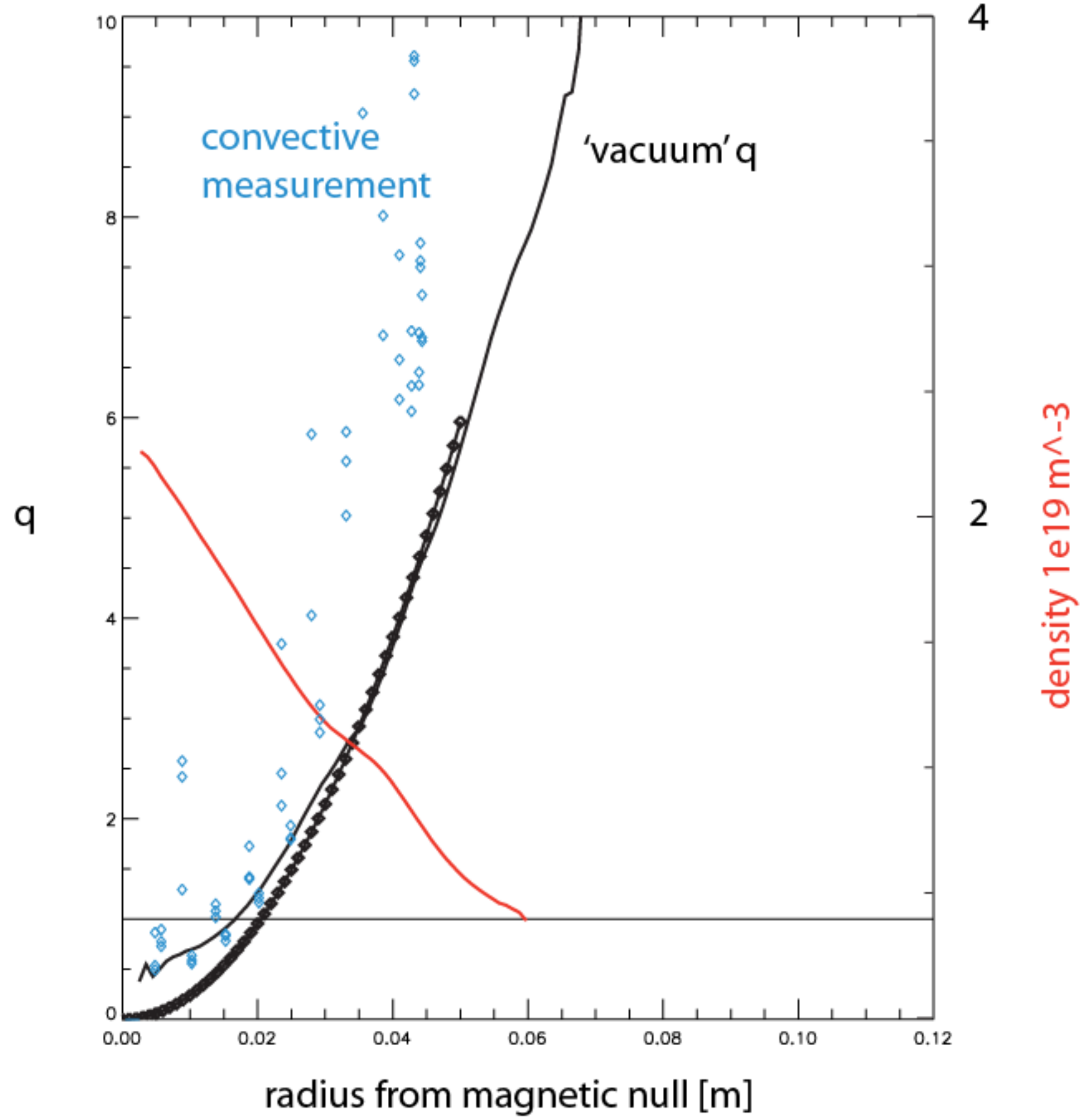
internal vs external

an internal kink has k.B=0 in the plasma and requires reconnetion on that surface to grow. it becomes a tearing mode.

RosenbluthPhysFluids16 1894 showed that this can cause an internal kink to saturate

density profile shows q=1 resonant surface is well within the plasma



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wall stabilization

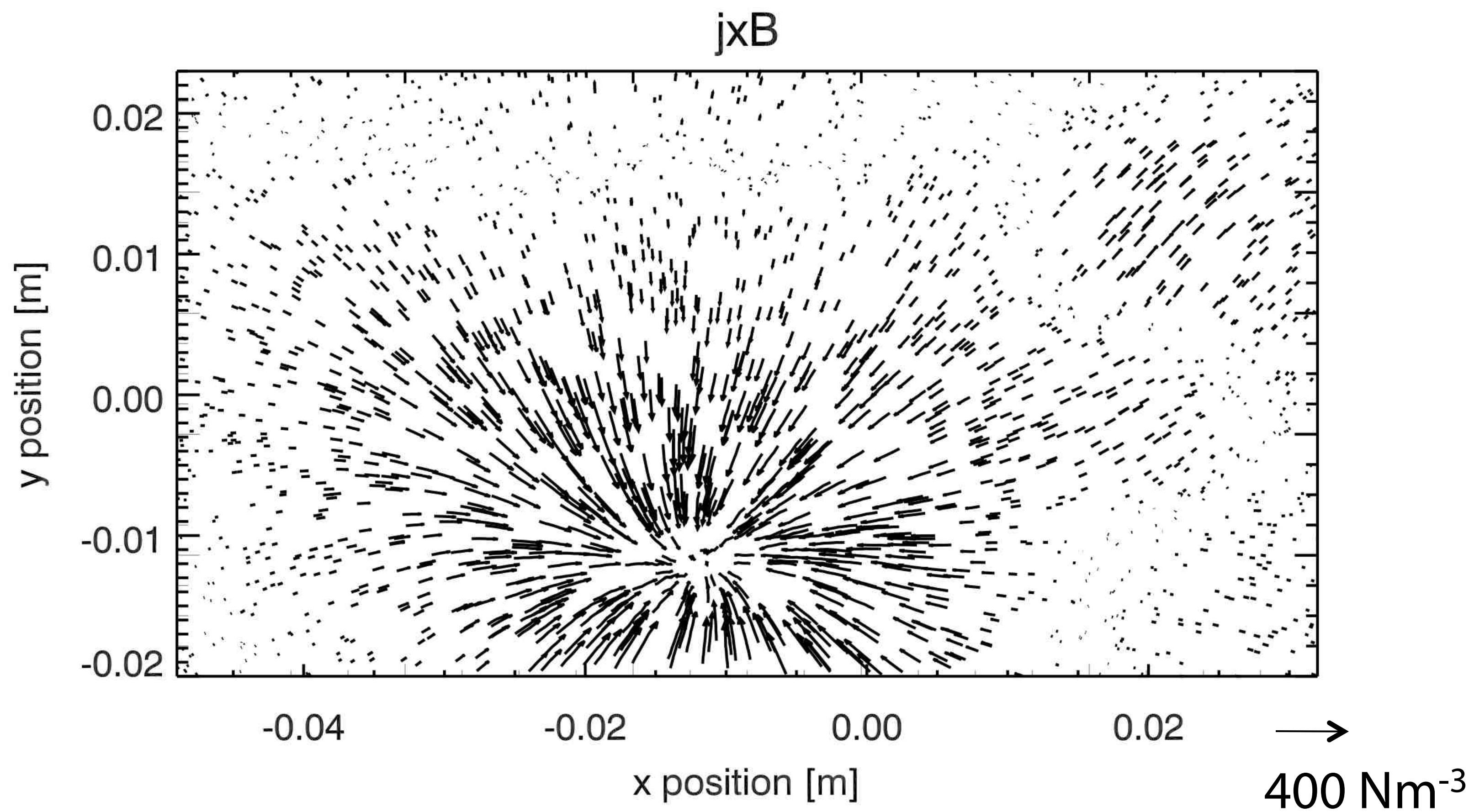
walls minimize the vacuum energy available to an instability. our wall is far away from the plasma, so it does not contribute to stability

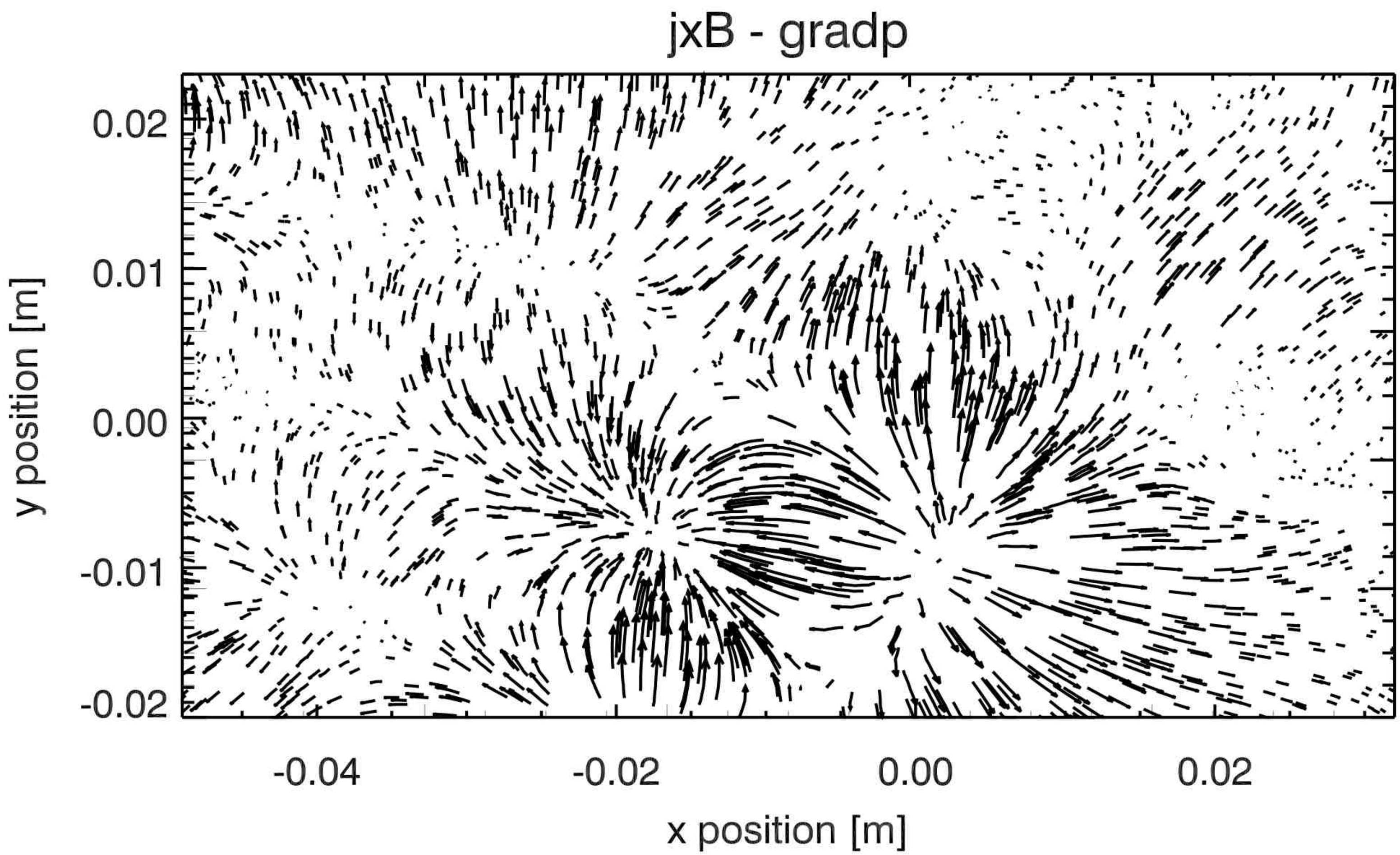
flow

flow causes the kink mode to rotate

shear flow can stabilize the kink
(ShumlakPhysPlasPRL 75 3285)

JxB_{perp} measured over entire cross section





jxB - gradp
0.02
0.01
0.00
-0.01
-0.02
y position [m]
-0.04
-0.02
0.00
0.02
x position [m]

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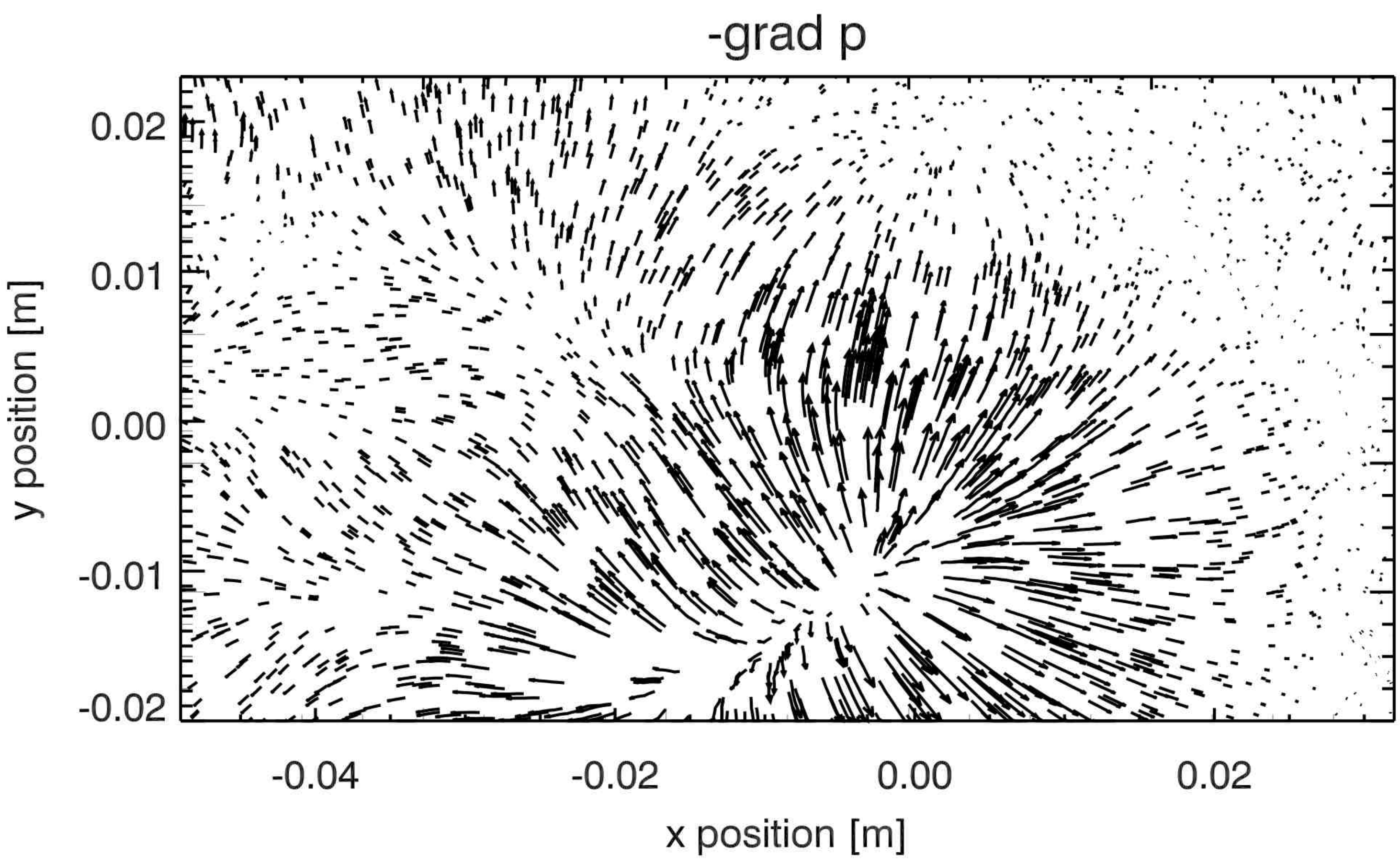

-grad p
0.02
0.01
0.00
-0.01
-0.02
y position [m]
-0.04
-0.02
0.00
0.02
x position [m]

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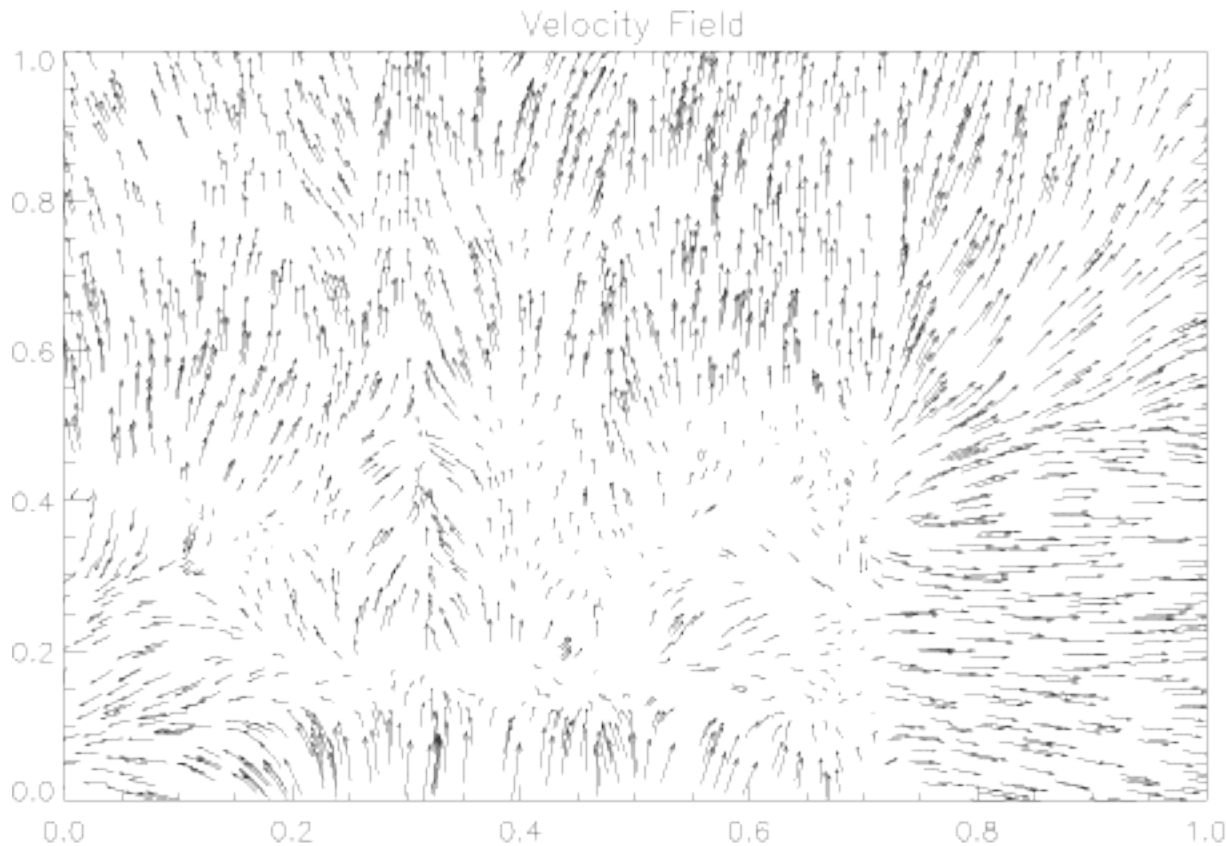
momentum balance:
rho.dv/dt = sigmaE + jxB – gradP



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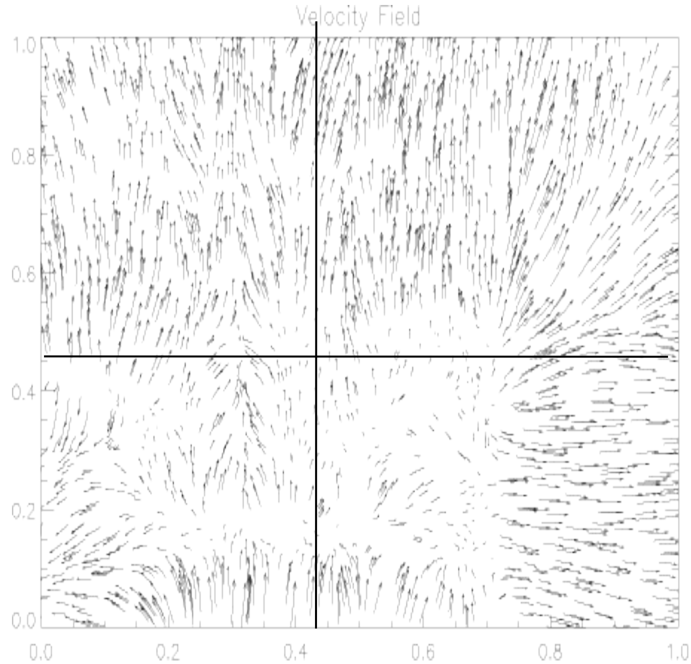
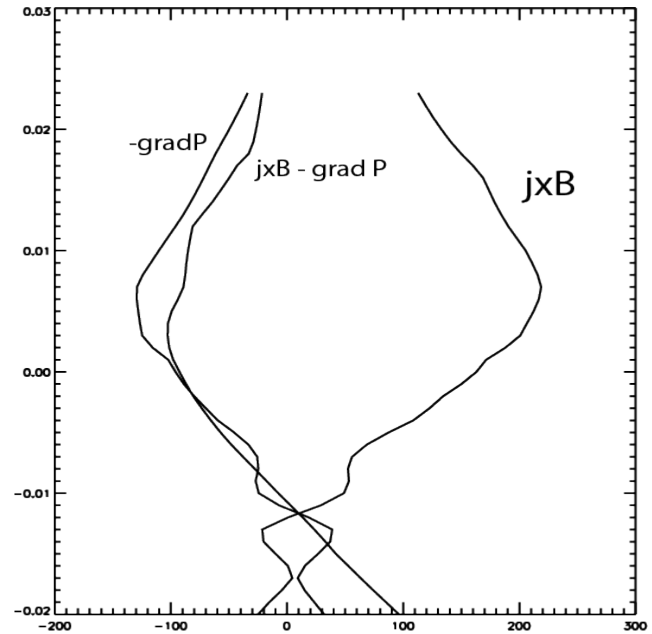
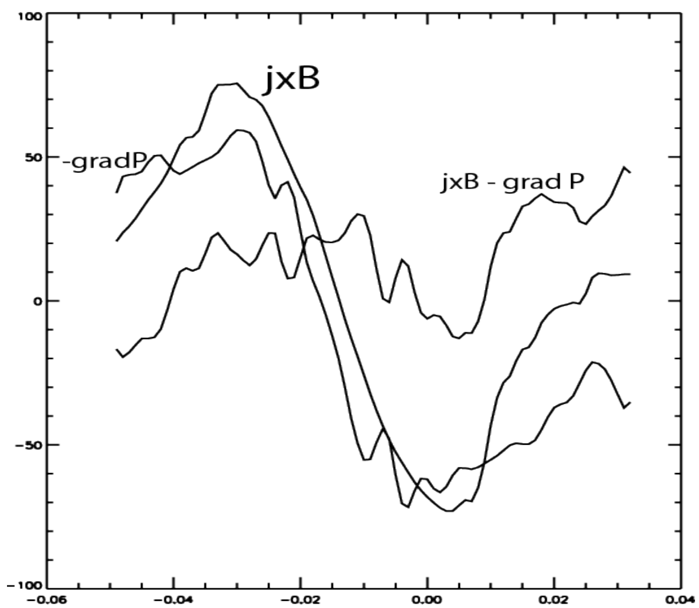

Velocity Field
0.0
0.2
0.4
0.6
0.8
1.0


-gradP
jxB - grad P
jxB


jxB
-gradP
jxB - grad P

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conclusion

- the kink mode can be unstable in the RSX plasma
- the kink saturates in a small range of current density
- RSX allows 3D measurement of field and plasma
- current density is measured above stability limit
- contours in density and temperature are not coincident

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bifurcated equilibria

- Rutherford (IAEA 1971) finds an equilibrium for an external kink mode

inertial forces

- the kink is solved in inertial frame
- when it rotates due to flow, the new solution is the sum of inertial solution plus coriolis and centrifugal forces
- (careyApJ699 362)